Does neuroscience research matters when I am teaching math?

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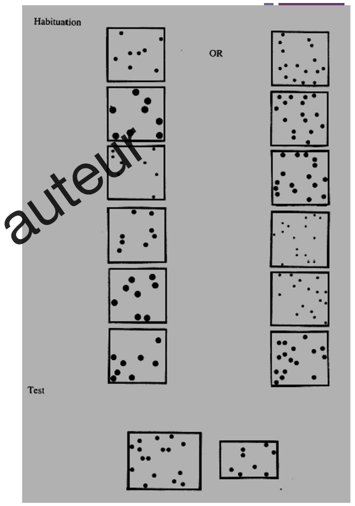
Do we have a brain made for numbers ?

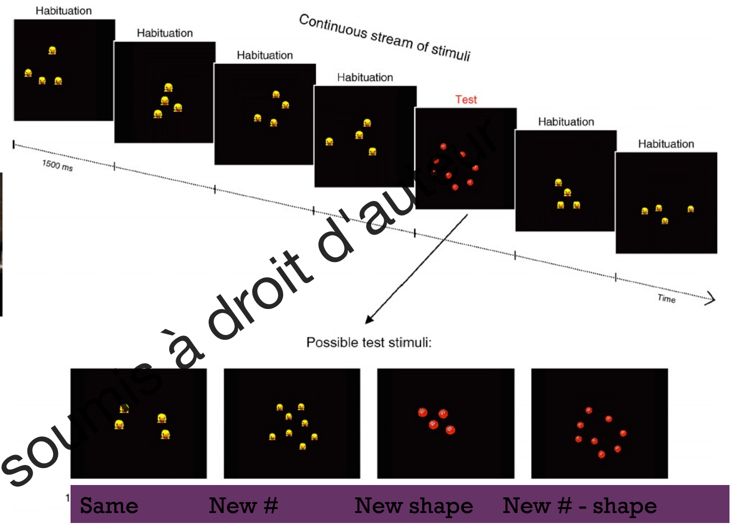
Babies

Xu & Spelke, 2000; Xu & Ariaga, 2007

- 6 month-old babies
  - Discriminate 8 vs. 16,
  - but not 8 vs. 12,
  - Can discriminate 16 vs. 32
  - But not 16 vs. 24
  - => Ratio of 1:2
- 9 month-old babies
  - 16 vs. 24
  - Ratio 2:3



=> approximate representation of number magnitude



- 3 months-old babies
- evoked potentials

Izard, Dehaene & al., 2008

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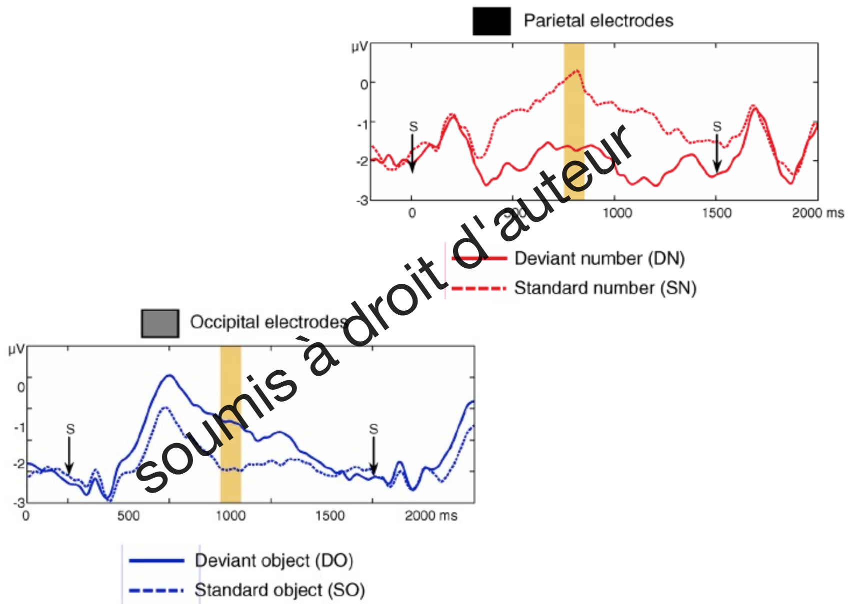

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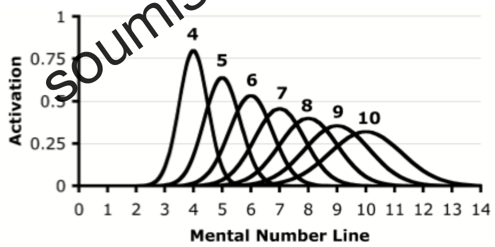
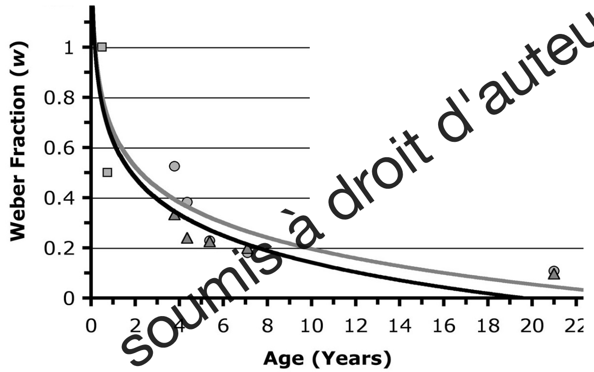
Children & adults

- Comparing the size of two collections
- Performance of older children and adults varies with the ratio between the 2 collections
- => an approximate representation of number magnitude (when counting is not allowed)



Number acuity (w) or the smallest discriminable ratio
Ratio n1/n2 => w = n2-n1/n1



increasing precision over development
(about 8/9 in adults)

Halberda, Feigneson, 2008, Devlp Psych

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Developmental dyscalculia

- Persistent and specific disorder of numerical development and mathematical learning
  - Proven by very weak performance in standardized tests of calculation and number processing
  - In the context of normal intelligence, normal schooling
  - Not due to sensory deficit

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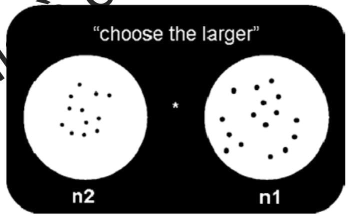
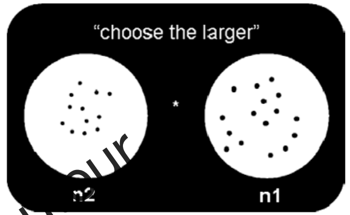
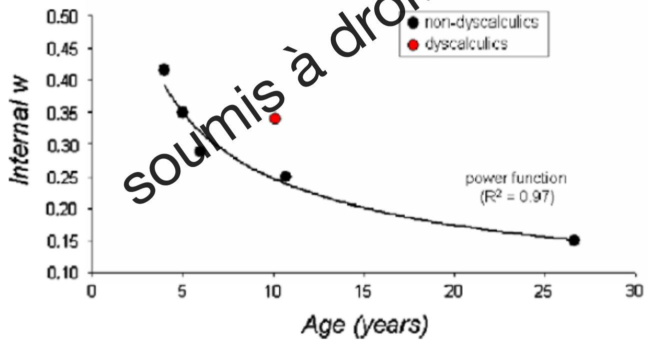
Dyscalculia: a problem in the approximate magnitude representation ?

- Weaker number acuity ?



- Population
  - children from age 3 to 6
  - dyscalculic children (10 y.o.)
  - control children (10 y.o.)
  - 20 adults





Piazza, M., Facoetti, A., & al, Cognition, 2010

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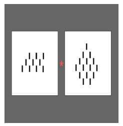
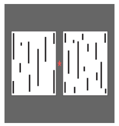
But divergent results

- Population
  - 45 children with dyscalculia (7 y.o.)
  - 45 control children (7 y.o.)
- **Tasks**
  - Non-symbolic



Easy condition



Difficult condition

Rousselle & Noël, 2007, *Cognition*

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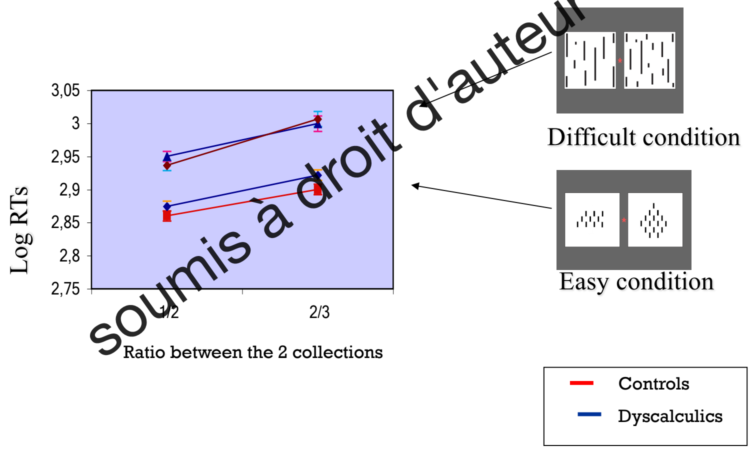
collections comparaison



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Divergent results

	age	Non-symbolic
De Smedt & Gilmore (2011)	6 years old	Dysca = controls
Rousselle & Noël (2007)	7 years old	Dysca = controls
Landerl & al. (2004)	8-9 years old	Dysca = controls
Iuculano et al. (2008)	8-9 years old	Dysca = controls
Piazza & al. (2010)	10 years old	Dysca < controls
Mussolin, Mejias & Noël (2010)	10-11 years old	Dysca < controls
Price & Ansari (2007)	12 years old	Dysca < controls

Weaker performance only in older dyscalculics
We should look for a another primitive deficit

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What is specific to human numerical cognition ?

- Not the detection of / discrimination between numerosities (monkeys, rats, dolphin can do it)
- The use of symbols to refer to numbers
  - Number words: *one, two, three, four …*
  - Arabic numbers: *1, 2, 3 …*

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Learning numerical symbols

- 1/ learn the sequence of verbal numbers
- 2/ discover the cardinal meaning of each number words
  - Slow process
  - Sequential

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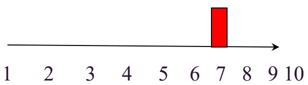
- For children who can count *one, two, three, four, five, six, seven, eight…*
- Give me
  - *One*: ± 36 months old
  - *One, two*: ±38 months old
  - *One, two, three*: ±42 months old
  - *One, two, three, four* and all the other numbers of their counting list: ±44 months old

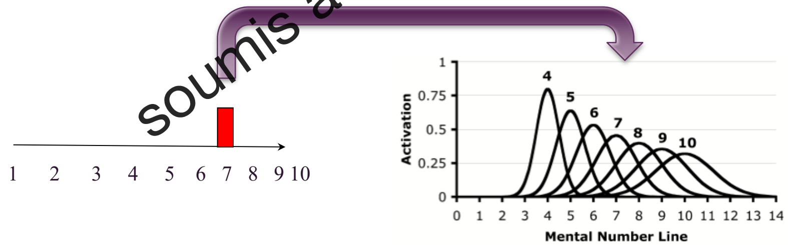
Wynn, 1992; Sarnecka & Carey, 2008

- Slow process because the child needs to build a new representation
  - exact
  - based on the successive function
    - The cardinal meaning of *n* = the cardinal of the preceding number in the counting list + 1



Sarnecka & Carey, 2008

- Then connect the cardinal meaning of number words to the approximate magnitude representation and are able to estimate the cardinal of a set



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Dyscalculia: a problem with the magnitude representation of symbolic numbers ?

- No one studied the fate of the young children who are slow in learning the cardinal meaning of number words
- But several studies used magnitude comparisons of Arabic numbers to measure the child's ability to process the magnitude of symbolic numbers

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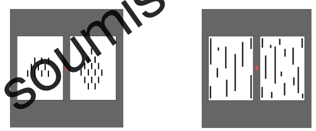
- Population
  - 45 children with Math Learning Disability (7 y.o.)
  - 45 control children (7 y.o.)
- Tasks
  - Non-symbolic
    symbolic



Easy condition *Difficult condition*

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Rousselle & Noël, 2007, *Cognition*

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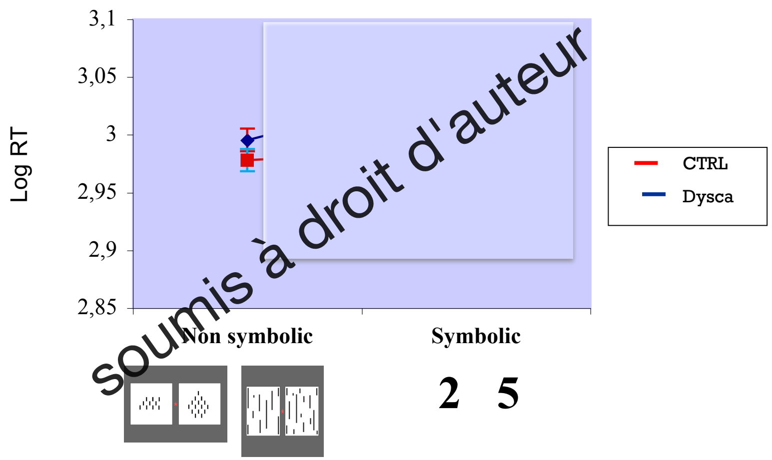

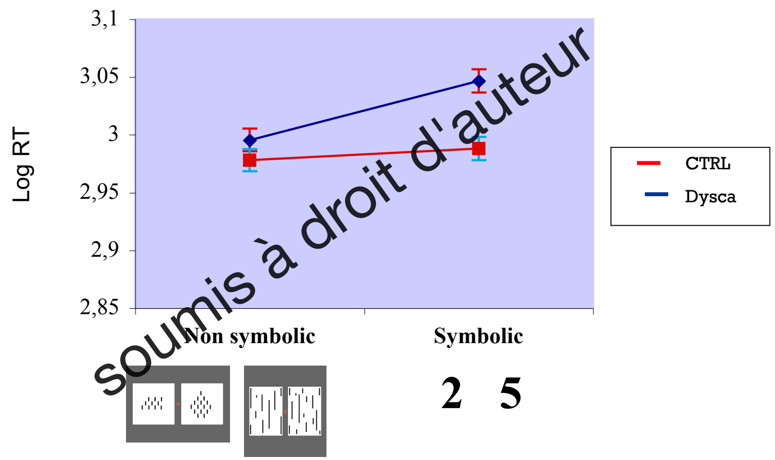

An early and stable deficit of processing magnitude of symbolic numbers

	age	symbolic	Non-symbolic
De Smedt & al (2011)	6 y.o.	Dysca < controls	Dysca = controls
Rousselle & Noël (2007)	7 y.o.	Dysca < controls	Dysca = controls
Landerl & al. (2004)	8-9 y.o.	Dysca < controls	Dysca = controls
Iuculano et al. (2008)	8-9 y.o.	Dysca < controls	Dysca = controls
Piazza	10 y.o.	-	Dysca < controls
Mussolin, & al (2010)	10-11 y.o.	Dysca < controls	Dysca < controls
Price & al. (2007)	12 y.o.	-	Dysca < controls

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How to help children with math difficulties ?

- "They do not intuitively grasp the size of a number or its value relative to other numbers" (Butterworth)
- Working at relating symbolic numbers (Arabic numbers or number words) with their meaning
  - By using correspondence with non-symbolic numbers (collections)
  - By using the space metaphor: the number line

Number race

- Aim: improving the number sense by going from dot sets to Arabic numbers
- Progressive game, adapts itself to the child's level

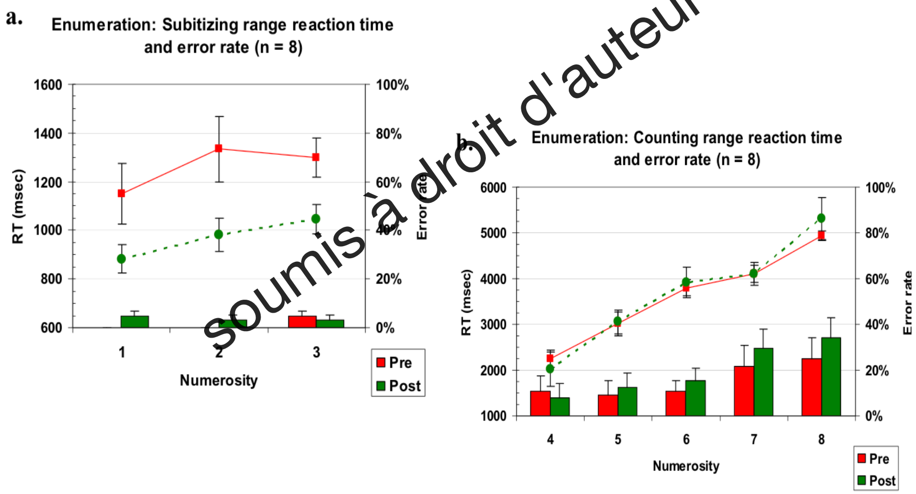
Wilson & al, *Beh & Brain Functions, 2006*

- Compare quantities (dot sets, Arabic digits), feed back with the oral numbers and the correct response
- Compute (add or substract) with dot sets, or with Arabic numbers

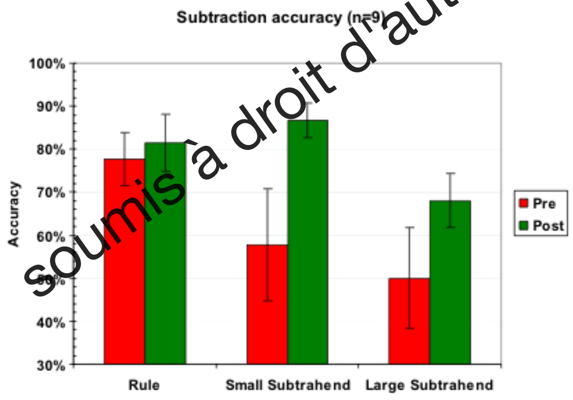
- 9 children with dyscalculia
- 30'per day, 4 days a week, 5 weeks
- Baseline before and after the training
  - Tedimath: counting, reading-writing numbers, base-10 understanding
  - Computer: addition, subtraction, dot counting (1-8), dot sets and Arabic number comparison

Wilson & al, *Beh & Brain Functions, 2006*

- Increase in counting speed for small quantities in the subitzing range but not for larger collections



- Improve accuracy in subtraction but not addition



n-n
n-0

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- Improve magnitude comparison speed for both dot sets and Arabic digits
- But …no control group

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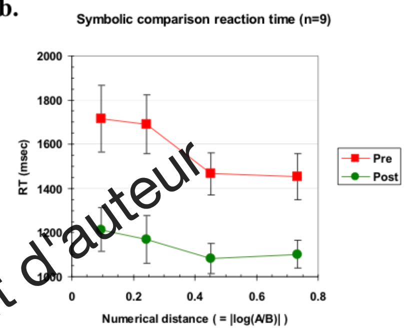

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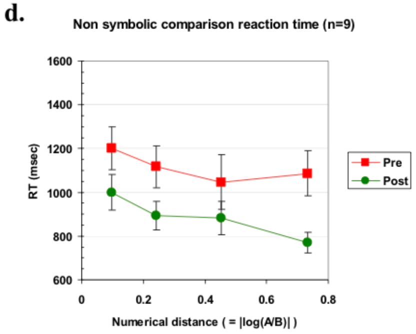
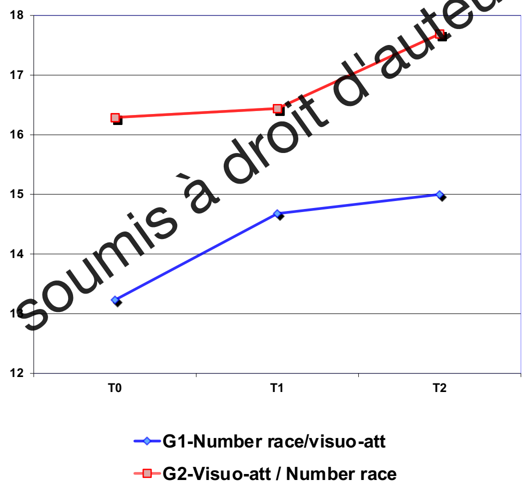


- 48 children, among which 6 with dyscalculia
- 30'/day, 4x/week, 4 weeks
- Two groups
  - G1: 4 weeks of number race, and then 4 weeks of visuo-attentional training
  - G2: 4 weeks of visuo-attentional training and then 4 weeks of number race

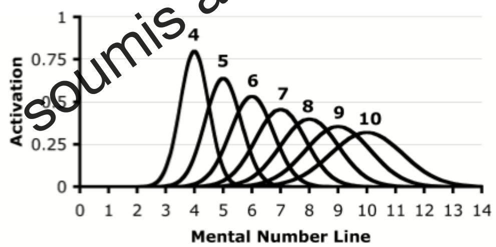
Verse, Hervé, Dewever & Habib, 2011

- Increase of performance on a scholar math test, after the number race only



Using the space metaphor

- Magnitude representation is an analogous representation associated with space
  - In our cultures: small (large) numbers associated with the left (right)



Using the space metaphor

- Siegler:
- When children are asked to position numbers on a number line, their precision in the task correlates with math performance from 1st to 4th grade (r ± .50)

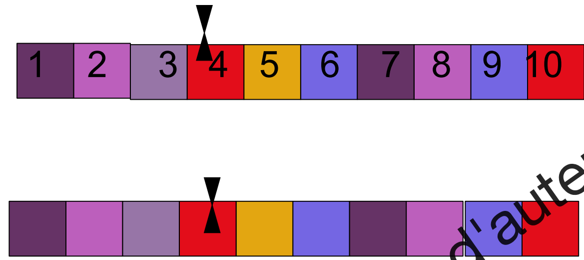
7 ?

0 10

- Frequent play with number board games at home is associated with better math learning

=> favouring this spatial analogy

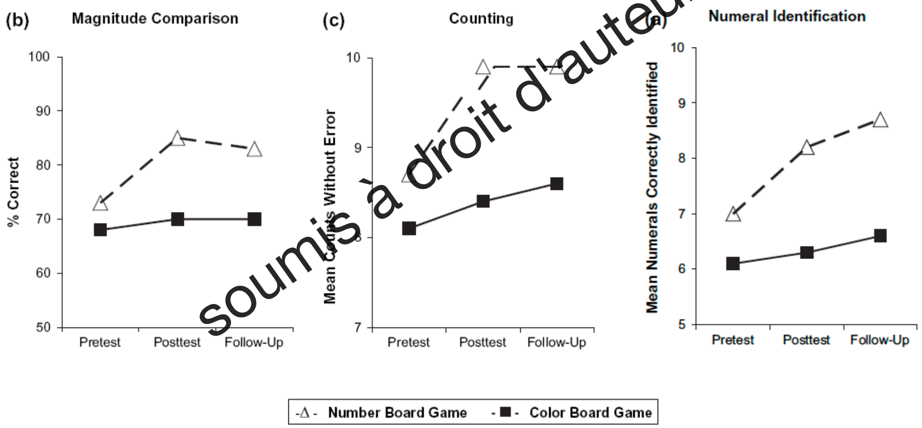
Siegler: Number line game



- Comparing the number board game & the colour game
- the child spin a spinner and then moves its token
  - by the number of steps indicated by the spinner, saying the number of each squares, for instance, "five, six"
  - to the color indicated by the spinner and saying out loud the colour names of the squares, for instance, saying "orange, blue"
- 4 yers old children (unselected)
- 5 sessions of 15-20 minutes

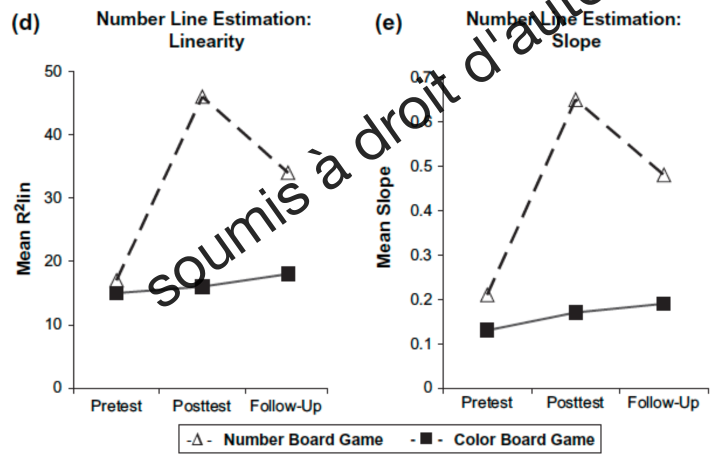
Ramani & Siegler, 2008

Compare the magnitude of 2 single-digit numbers (1-9)
count from 1 to 10
Name the digit



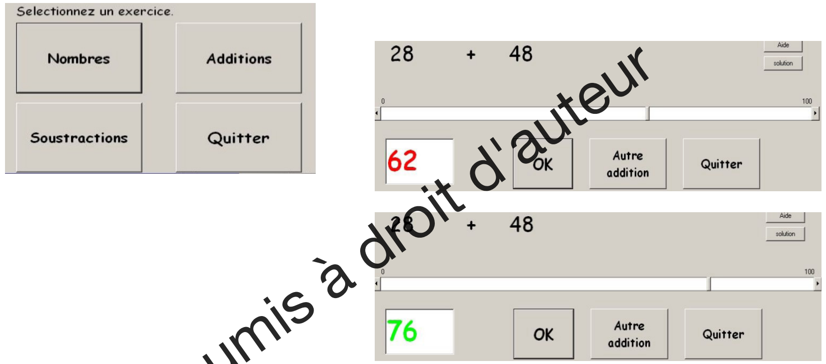
Ramani & Siegler, 2008

Position a single-digit number on a 1-10 line



+ For larger numbers in the context of arithmetical operations

The estimator



The child first reads aloud the problem
Using the cursor, the child indicates the position of the approximate answer on the number line.
If far from the correct answer, the number corresponding to the marked position appears in red and the child has to restart its estimation.
If close to the correct answer, the correct answer appears in green.

Vilette, Mawart & Rusinek, 2010

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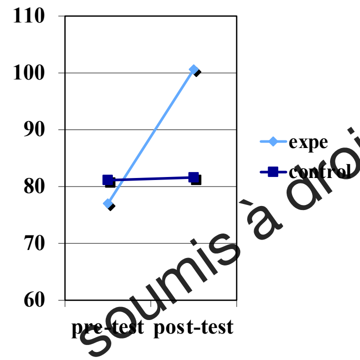
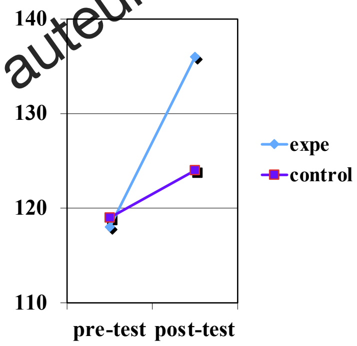
- Method
  - 20 children, 11 y.o., 2 years behind in math
  - 2 groups
    - Expe group: uses the estimator + and -
    - Control group: uses another computer program on the same calculations but which only requires exact answers
  - 7 sessions of 30'
  - Baseline: Zareki-R

Vilette, Mawart & Rusinek, 2010



SN on Additions-subtractions



Total SN score on the Zareki battery

Vilette, Mawart & Rusinek, 2010

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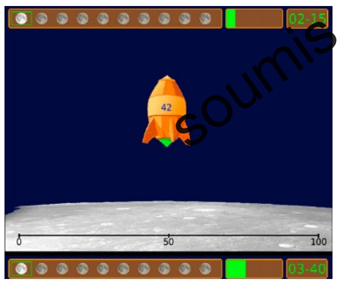
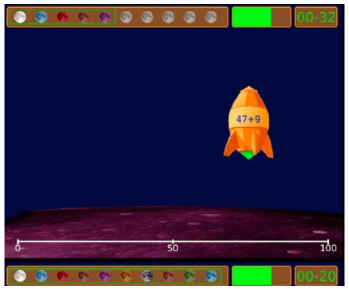
Rescue calcularis

- estimate the position of a number, or of the result of an addition or a subtraction, on a number line marked 0 to 100 at the extremities.
- If estimation is within a range of ±10 of the correct position, the exact position is given as feedback.





Kucian et al., 2011, NeuroImage

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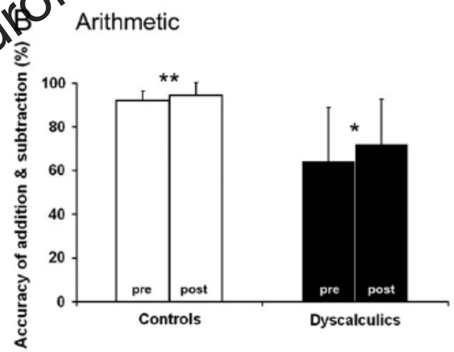
- 16 control and 16 MLD children (± 9 y.o.)
- 25 times for 15' within a 5-week period.
- Increase performance in both groups in arithmetic
- And in positioning numbers on a number line



Role of the body ?

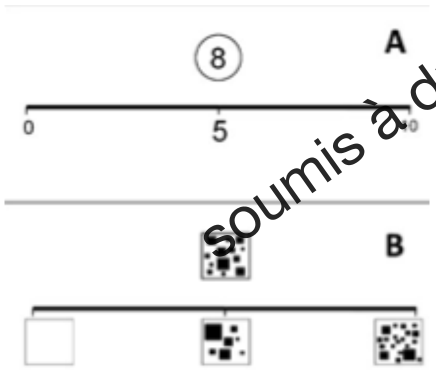
- « *embodied cognition* »: the motor system is not solely used for action, it also contributes to cognitive representations
- Comparison of two numerical trainings: with or without the spatial involvement of the body

- 18 children aged 5-6 yers old
- 2 trainings
  - Experimental including full-body movement and space
  - Control
- design
  - ½ of the children: expe then control
  - ½ of the children: control then expe
  - 3 sessions, 10-15 min for each program

Fischer, Moeller …Nuerk (2011). Psycho Bull Rev

Experimental	Control

- Comparison to a standard
- Answer: Jumping on the left or right on the dance mat



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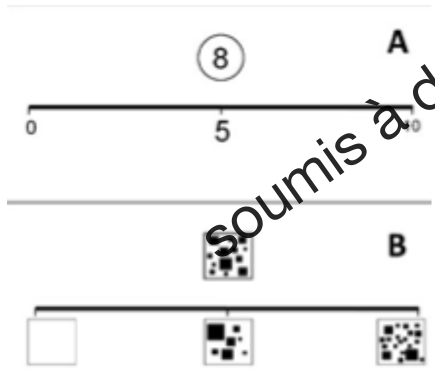
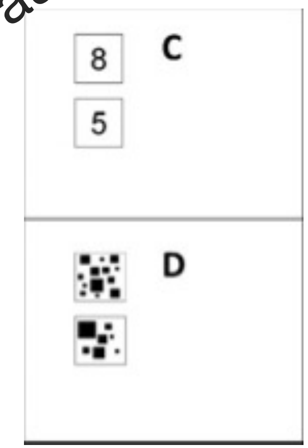
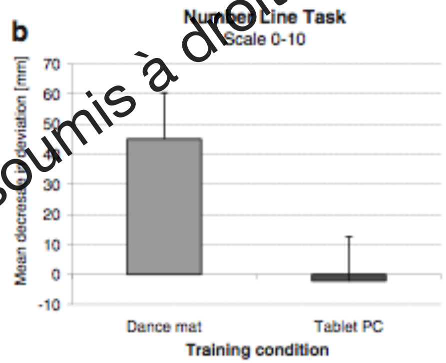


- Comparison to a standard
- Answer: push on the side of the bigger using a tactile PC screen



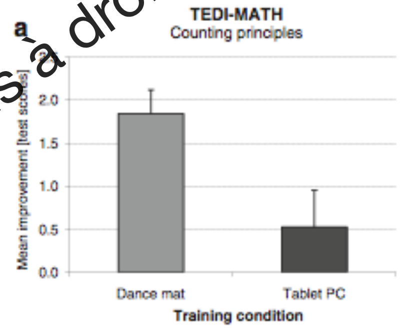
Results

- Number positioning on a number line (0-10 or 0-20)
  - No ≠ for 0-20 but larger increase of precision for 0-10 after the experimental training than the control training



Results

- Tedi-math
  - Single effect on the verbal counting
  - Larger progress after the experimental training than the control training



Conclusion

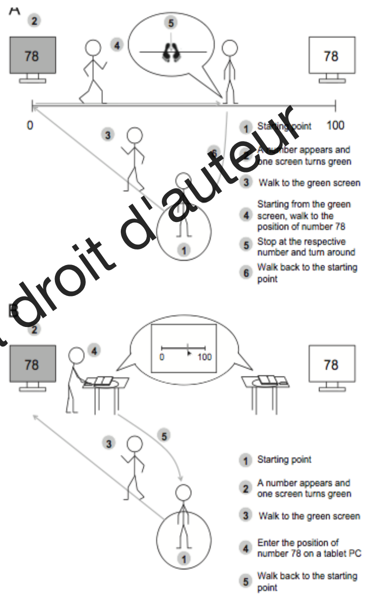
- Yet, what is important: body movement or spatial representation of numbers?

+ Method

- 33 1st graders
- Training game: estimate the position of a number on the number line (0-100)
  - Experimental (embodied) condition
    - The number line is on the floor (1.5m – 3 m), the child has to walk along the number line
  - Control condition
    - The number line is on a tabled PC (11cm – 23 cm), the child uses the computer mouse
- 3 sessions of 24 items; half of the children start with the experimental and then the control; reverse for the other children

Experimental – embodied

Control condition



Results

- Larger increase after the experimental training in
  - Number line positioning (+16% vs. +13%)
  - Arabic number comparison
  - Single digit addition (single-digit): significant improvement in the experimental condition only: +10% versus -10%
- Similar and significant increase in
  - Sets comparison
  - Base-10 understanding

Take-home message

- Our brain is made for processing quantities approximately
- The counting list is a symbolic tool that allows building a representation of exact number
- Dyscalculic children have difficulties in grasping the size of symbolic numbers or their values relative to others
- Help them by
  - Going from material (non-symbolic numbers) to symbolic numbers
  - Using the space metaphor and the number line
  - Using experience with the full body to feel in the body the magnitude of numbers

Thank you !

Sandrine Mejias

Christophe Mussolin & Gaelle Meert

Laurence Rousselle